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Woods Hole Oceanographic Institution

Preliminary Results Of The Effects Of SURTASS-LFA Sonar On Singing Humpback Whales

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May 2000

Technical Report

Funding was provided by the Office of Naval Research under Contract No. N00014-97-1-1031.

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Abstract:

The singing behavior of humpback whales exposed to SURTASS-LFA sonar was monitored in Hawaii during March 1998. An observation vessel towing a hydrophone array followed individual singers continuously recording their songs and the received level of the sonar near the whale. At least 2 complete songs were recorded before commencing a 60min 42s long playback, which consisted of ten 42s signals transmitted every 6 min. by a U.S. Navy vessel. Observations continued into the post-exposure period. Song spectrograms were broken into themes and phrases using visual analysis and aural scoring. 23 focal follows were conducted; 5 were control follows with no playback. In 9 follows the whale sang throughout the playback, in 4 the whale stopped singing when it joined another whale and in 5 it stopped presumably in response to the playback. We recorded at least one complete song in all three experimental conditions from six individuals. These singers sang longer songs during (13.75min) than before (10.68min) or after (10.58min) the playback (model III ANOVA, p=0.047, n=6). No differences were found in theme order (χ^2_2=3.273, p=0.195). Song cessation and song duration responses did not scale with sonar received level. High variability in individual responses may indicate that some males were more sensitive to the sonar than others.

1. Background

There has been concern that increasing levels of man-made noise in the world's oceans could affect marine life, and especially marine mammals, who rely on sound for communication, orientation and predator/prey detection. Because many sources of underwater noise are predominantly low-frequency (<1kHz), and low-frequency sounds propagate very efficiently underwater, there is a potential for large-scale effects. In 1996, the Navy officially announced the undertaking of an Environmental Impact Statement (EIS) to cover the use of the SURTASS-LFA (hereafter "LFA"), a low-frequency sonar system developed for the detection of submarines (Federal Register Announcement 61, 18 July 1996). The sonar system combines a calibrated low-frequency sound source and a state-of-the-art system to measure and model acoustic propagation with a towed horizontal line array as a low-frequency passive tracking system.

The EIS process presented a unique opportunity to acquire scientific data on the behavior of free-ranging whales exposed to controlled experimental playback of underwater low-frequency sound. A three-phase scientific research program (SRP) was developed to acquire scientific data on the potential response of different species of mysticete whale to the LFA sonar system. Mysticetes may be particularly at risk from exposure to low-frequency noise as they produce low-frequency sounds thought to be used for communication. Phase I was conducted in September-October 1997 off San Nicolas Island, CA, to monitor the behavior of fin and blue whales, which were primarily feeding. Phase II was carried out in January 1998 in the area of Pt. Buchon, CA, along the course of migrating gray whales. Phase III, reported here, was completed in March 1998 off the Big Island, Hawaii, and focused on the singing behavior of humpback whales. The NE Pacific humpback population was chosen as study population because there was a significant amount of baseline data on humpback behavior and ecology in the Hawaiian Islands.

Humpback whales are sighted most commonly in the Hawaiian Islands from January-April during their breeding season. During the breeding season males sing complex songs which seem to function as a reproductive advertisement display (Tyack, 1981). Songs are a sequential pattern of sounds organized in a hierarchical structure (see song analysis section in the methods), that the whales repeat in song sessions often lasting several hours. At any one time all of the singers in a population sing roughly the same song, although changes in the song occur throughout a breeding season and over the years (Payne *et al.*, 1983, Guinee *et al.*, 1983). There have been a number of studies on the effect of sonars (Maybaum, 1990 & 1993) and of other noise sources (Baker and Herman, 1989; Frankel and Clark, 1998; Todd *et al.*, 1996; Watkins, 1986) on humpback whales. These studies principally focused on visual observation of surface behavior. The only study focusing on possible effects of man-made noise on the singing behavior of humpback whales found that singing humpback whales decreased the duration of phrases and units when exposed to boat noise, but that other song features appeared to be unaffected (Norris, 1994).

The goal of phase III of the LFA SRP was to assess short-term responses of singing humpback whales to the LFA sonar. Two different methods were employed to "follow" a subject whale. One method used passive acoustic localization from the playback vessel to track singers and monitor singing behavior throughout the playback. The other method, reported here, combined visual observations of surface behavior with acoustic monitoring of singing behavior from a small observation vessel that followed a focal singing whale. The hydrophone array on the observation vessel was also used to measure the received level of the sonar transmission near the whale. A shore station was also used to monitor inshore whales, especially mothers and calves.

2. Methods

An A-B-A experimental design was used to assess changes in behavior as a function of playback (Hopp & Morton, 1998). Baseline behavioral data were obtained by observing surface and acoustic behavior for at least two complete song cycles before commencing a playback. Each playback consisted of a 42s signal transmitted every 6min for ten repetitions, yielding a total duration of 60min 42s. Observations of surface and singing behavior were continued in the post-exposure condition.

The LFA signal used in the playbacks consisted of three hyperbolic frequency-modulated (HFM) sweeps, followed by three continuous wave (CW) tones, followed by three hyperbolic frequency-modulated (HFM) sweeps in the 100-500 Hz frequency band (Fig. 1). The system was operated in omni-directional mode, transmitting sound in all directions. The source level (SL) was kept constant during each experiment but was changed amongst experiments, depending on propagation conditions, to achieve the intended received level at the focal whale. To minimize the risk of harm to the subject whale, the maximum RL of the sonar signal at a focal whale was not to exceed 155 dB.

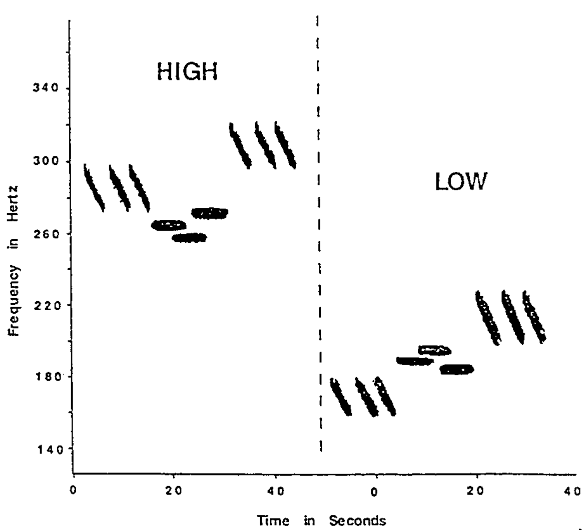

Fig. 1 – Spectrogram of the two LFA signals used during phase III in March 1998. The signal consists of three hyperbolic frequency-modulated (HFM) sweeps, followed by three continuous wave (CW) tones, followed by three hyperbolic frequency-modulated (HFM) sweeps in the 100-500 Hz frequency band.

2.1 Data collection

The research was conducted in the waters off the West Coast of the Big Island, Hawaii (Fig. 2), during March 1998, and involved the use of two vessels: a playback vessel (U.S. Navy R/V *Cory Chouest*) and an observation vessel (7m rhib). Singers were found acoustically using a hydrophone deployed at different locations. During the acoustic search phase, recordings were made at each listening station on a Sony D-8 DAT recorder. Once a loud singer was heard, it was identified by correlating an increase in song volume with the singer's dive (Tyack, 1981).

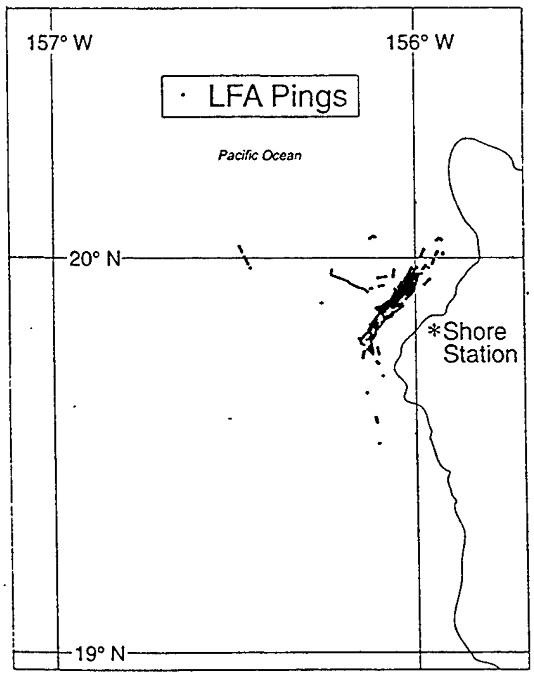

Fig 2 - Research area for phase III off the West coast of the Big Island (Hawaii). The location of the shore observation station is marked with an asterisk. The dots indicate the location of each playback transmission throughout the study.

Once the correlation between song and dive cycle was established, we deployed a towable hydrophone array (Miller & Tyack, 1998) to start a continuous follow of the singer. The use of a towed hydrophone array allowed continuous recording the singing behavior of individual whales' throughout the experiment. Two channels of the array (±3 dB from 100Hz to 20 kHz; sensitivity of –152dBV/μPA) were recorded onto a TEAC DAP-20 DAT recorder. The received level of the LFA sonar near the singer was measured from these recordings. Energy was summed over a 75 Hz band centered on the LFA signal and averaged over the entire duration of the signal using Canary®. The recorder gain and A/D conversion steps were calibrated by recording and measuring a tone of known amplitude. In 5 cases, for which the tape recordings were not calibrated, the received level was estimated using an extensively tested transmission loss model.

The use of the observation vessel and a towable hydrophone array allowed us to conduct focal animal sampling on the subject or "focal" animals (Altmann, 1974). Using this method we continually recorded all occurrences of pre-defined behaviors, such as song production and surfacing events in all experimental conditions. By comparing

behaviors in the different conditions, we can directly test hypotheses related to potential changes in behavior of individual humpback whales. By sampling individual animals using an A-B-A playback design we directly control for inter-subject variability, which may decrease the power of studies that observe groups of animals or that pool data from different individuals. Selection of a subject for focal animal sampling from an independent platform before transmission also reduces the bias toward sampling less sensitive animals which is inherent in studies that observe subjects from the noise source itself.

A concern with using this method is that the observation vessel itself might affect the behavior of the subject, reducing the ability to observe effects of the LFA sonar. We attempted to minimize any such effects by carefully driving the boat at low speeds whenever possible, and keeping 200-300m away from the subject. Because the observation vessel followed the subject in all exposure conditions, disturbance from the observation vessel should not bias study results. However, strictly speaking, this study evaluated the additional impact LFA sounds have on a singing whale that is already being followed by a small vessel. A baseline condition of one boat near the focal whale is not uncommon, as many small vessels operate near singing humpback whales.

At each surfacing event of the focal whale we confirmed that it was the singer monitored with the towed array. Three cues were used to confirm that our subject whale was the singer: 1.) increase in song level correlated with dive; 2.) surfacing during particular portions of the song; and 3.) increase in song level as we approached our subject's surfacing location. Time and location were read off a hand-held GPS, and bearing to the whale and the whale's heading were obtained using a hand-held digital compass. The range to the focal whale was measured with laser range-finding binoculars (Leica Vector DAES, 7x42) whenever possible, or estimated by trained visual observers whose estimates were calibrated by the range-finder. All data were recorded on a data sheet and entered later in a computer database. Photo-identification pictures of flukes and the dorsal fin were taken for each surfacing sequence to confirm the focal whale ID throughout the experiment. Subsequent matches of photo-id's confirmed that our focal did not change during the follow. A "focal follow" would be ended after we observed behavior for at least 3 song cycles in the post-exposure period, or if we lost the focal whale or weather conditions deteriorated.

2.2 Song Analysis

All recordings were first visually and aurally scored using a Kay sona-graph 5500. Recordings were broken into songs, themes and phrases according to Payne and McVay (1971). A song is a series of themes repeated in a fixed order, a theme is a series of similar phrases and a phrase is a series of units, where a unit is defined as "the shortest continuous sounds to the human ear when played in real time". Each theme was given a progressive number starting from 1 (see Appendix 1). Song beginning was defined as the first unit of theme 1 that occurred after the typical surfacing sequence (themes 4 and 5). A song was defined "aberrant" if theme order was altered (Frumhoff, 1983). Songs were digitized and stored as a .wav files (sampling rate 44.1 kHz). After 6x-down-sampling

the signal, spectrograms were computed using an FFT window of 512 points, and 50% overlap. This resulted in a temporal resolution of 34.8 ms and a frequency resolution of 14.4 Hz. Gray-scale song spectrograms were then printed from 0 to 2500 Hz with a dynamic range from 85 to 125 dB.

Only complete songs (e.g. from theme 1 to the beginning of next theme 1) were used in the analyses. A song (or theme) was considered to be in the playback condition if an LFA transmission occurred at any point in the song. Song duration was measured directly from the spectrograms using a ruler (see data sheet, Appendix 4). Cessation of song was scored in the field and confirmed with subsequent analysis of the spectrograms. Because singers naturally stop when joined by another whale (Tyack, 1981), we visually recorded when other whales joined our focal. Song cessation during the exposure condition was scored as: 1.) no cessation, 2.) cessation with a join, or 3.) cessation without a join. Cessation of song without a join during playback (#3) was considered a possible reaction to the LFA playback. This may overestimate reactions to playback, because singers in baseline conditions may also stop singing without joining (Tyack, 1981).

2.3 Statistical tests

There has been considerable controversy about the appropriate unit of analysis for playback experiments (Hopp and Morton, 1998). Because the hypothesis we tested is whether or not whales sing longer songs during playback, the most appropriate approach is to treat each individual subject as the basic unit of analysis (Machlis *et al.*, 1985). However, this analysis often leads to low power to detect an effect due to small sample sizes. This experiment took place in a context where we are as concerned with β or type II error (concluding incorrectly that there was no effect due to low power of the test) as α or type I error (accepting an effect that may have been due to random variation). This concern follows a precautionary approach for environmental issues (Lehmann, 1958; Peterman & M'Gonigle, 1992).

Using the singer as the unit of analysis, we used a model III ANOVA to compare the song length of singers before and during playback. This two-way model treats subjects as a random sample from a population of singers (which matches how we selected singers in the field) and tests the effect of a "fixed" factor (the LFA sonar) on song length where each song is considered an independent observation. Thus, this test assumes that there is no serial correlation between songs produced by a singer in a song session. We tested this assumption by measuring the first order auto-correlation of the duration of songs recorded in the pre-exposure condition and in control follows ($z = 0.118$, $p > 0.20$, $N = 39$, power = 89%). We also calculated the power ($1-\beta$) of the model III ANOVA test to observe an effect (Zar, 1984).

To explore if theme order was altered by the LFA playback, we compared theme-transition matrices for all songs in the pre-exposure, exposure, and post-exposure conditions. Differences in the matrices were tested using χ^2-test (Zar, 1984). A binary logistic regression model was used to investigate whether the maximum received level of

the sonar was a good predictor of either the likelihood of song cessation or a change in mean song duration during the playback condition. In the model the maximum received level of the sonar was the independent variable, and the whales' behavioral response was the dependent variable (Systat, 1997).

3. Results

A total of 23 focal follows were conducted in which 16 individuals were subjects of 18 playback follows, and 5 were control follows with no playback. Three playback follows were discarded from the analysis of song duration because they did not include at least one complete song in pre-exposure and exposure condition, and songs from two individuals sampled on two different focal follows were pooled (animal ID: M and R, see Table 1). Of the 15 follows with playback, 6 had at least one complete song in all the experimental conditions and 13 had at least one complete song in both the pre-exposure and exposure conditions (see Appendix 3 for song duration). The maximum received level of the LFA sonar measured near the animals ranged from 115 dB to 150 dB re 1μPa (Table 1).

Focal no.	**Animal ID**	**Song Sample**			**Max RL** (dB re 1μPa)	**Cessation of song vs max RL**	**Δ song duration vs max RL**
		pre	**exp**	**post**			
1march-1	A	3	3		132	✓	✓
1march-2*	B	*			*	*	*
2march-1	C	6	1		122	✓	✓
3march-1	D	3	6	5	133	✓	✓
4march-1	E	3	2		126	✓	✓
4march-2	F	2	4		124	✓	✓
5march-1	G	2			137	✓	✓
5march-2	H	3	4		122	✓	✓
6march-1	I		6		124	✓	✓
8march-1*	J	*			*	*	*
10march-1	K	2	6	8	142	✓	✓
10march-2	L	2	4	1	150	✓	✓
12march-1*	E	*			*	*	*
15march-1	M		1		129	✓	✓
16march-1	N	*			*	*	*
17march-1	M	2	3	2	115	✓	✓
18march-1	O	3	4	4	132	✓	✓
20march-1*	P	*			*	*	*
20march-2	Q	9			121	✓	✓
27march-1	R	5	3	3	150	✓	✓
27march-2	R	2	1		138	✓	✓
28march-1	S	1	3		140	✓	✓
29march-1	T	5	2		133	✓	✓
TOTAL: 23	**20**	**13**			**18**	**18**	**18**
5 controls 18 playbacks	whales	6 whales pre,exp,post 13 whales pre,exp			playback follows	playback follows	playback follows

Table 1 – Summary of results and data analyses. Numbers in the third column refer to the number of complete song recorded in each experimental condition. * = control follow; ✓=used in the analysis.

A total of 215 songs were scored in all conditions, of which 152 were complete songs (e.g. from theme 1 to the beginning of next theme 1). Song analysis resulted in the identification of five themes, defined as "fundamental" themes (Fig. 3; Payne, 1978). Two very rare themes, defined as "optional themes" (Payne, 1978), were produced by a small number of singers. Themes 1 and 2 were the most variable both in the number of units per phrase and unit types with 3 and 4 alternative phrase types, respectively. (called "shifting themes"; Payne and Payne, 1985). Themes 3-7 were more consistent, with occasional differences in the number of units per phrase but not in unit types. Different themes appeared to have different duration within and between individuals.

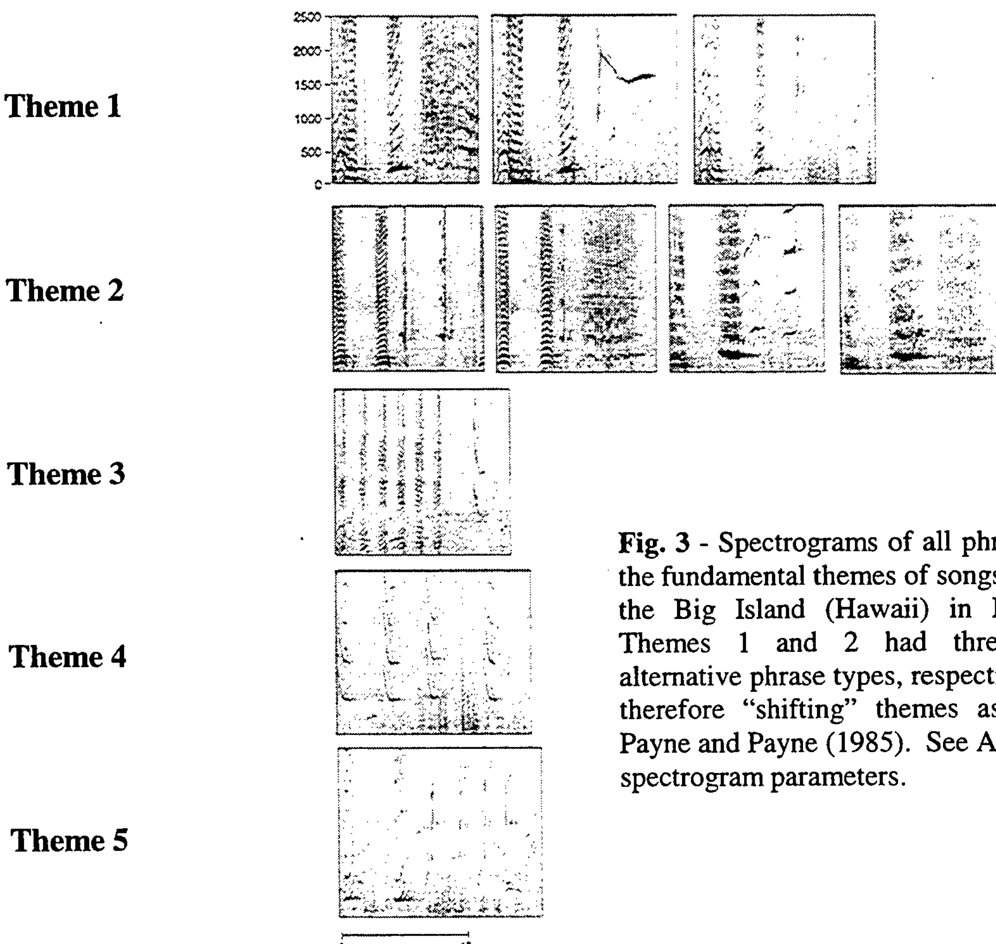

Fig. 3 - Spectrograms of all phrase types for the fundamental themes of songs recorded off the Big Island (Hawaii) in March 1998. Themes 1 and 2 had three and four alternative phrase types, respectively, and are therefore "shifting" themes as defined by Payne and Payne (1985). See Appendix 3 for spectrogram parameters.

3.1 Song duration

Song length of the 6 singers sampled through all three phases of playback was longer during the exposure condition (mean song length 13.75 min ± 0.72 SE, n=6), than before playback (mean song length 10.68 min ± 0.95 SE, n=6). Song length returned towards baseline values in the post-exposure condition (mean song length 10.58 min ± 0.70 SE, n=6). The average number of songs per singer in the pre-exposure, exposure and post-exposure conditions was 3.2, 4.7 and 3.8 respectively. The effect of the exposure condition using the model III ANOVA was significant at P=0.047 ($F_{2,10}$=4.200, power=50%), see Figure 4.

Song length of the thirteen singers for which at least one complete song was recorded during pre-exposure and exposure condition was longer during playback (mean song length 14.23 min ± 0.70 SE, n=13) than before (mean song length 12.45 min ± 0.76 SE, n=13). The average number of songs per singer in the pre-exposure and exposure conditions was 3.2 and 3.6, respectively. The effect of the exposure condition using the model III ANOVA was marginally significant at P=0.096 ($F_{1,12}$=3.260, power=32%), see Figure 5. Note the low power of the test.

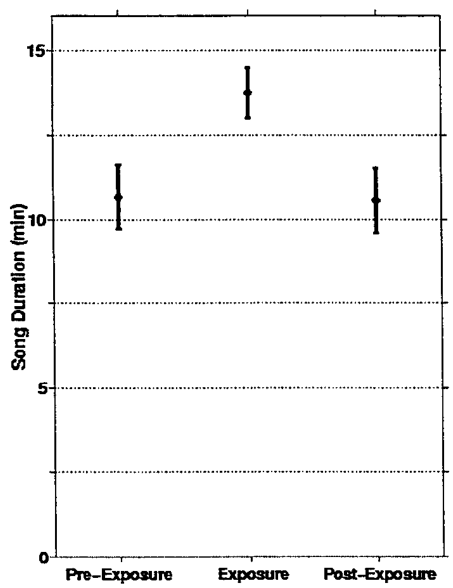

Figure 4 - Song duration across experimental condition pooled by singer (model III ANOVA, $F_{2,10}$=4.204, p=0.047, n=6, power=50%).

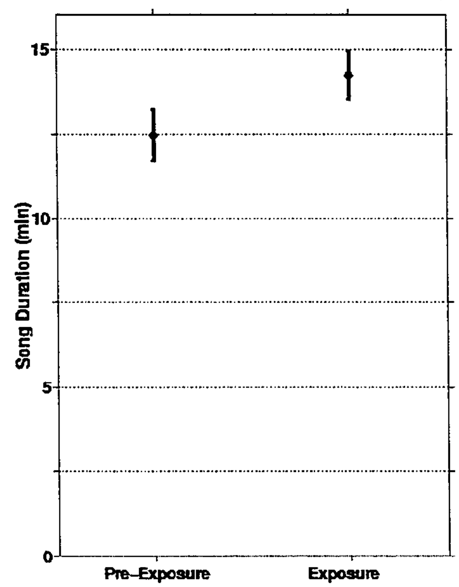

Figure 5 - Song duration across experimental condition pooled by singer (model III ANOVA, $F_{1,12}$=3.260, p=0.096, n=13, power=32%).

3.2 Theme transitions

Theme order was dominated by a primary theme sequence from theme 1 to 5, although several aberrant theme transitions were observed in all playback conditions (Fig. 6). We used a χ^2-test to compare the theme transitions in all songs produced by the six singers with a complete song in all three experimental conditions (see Fig. 4). Observed theme transitions were first organized into matrices where columns and rows were preceding theme and following theme, respectively. The experimental condition of theme transitions was determined by the experimental condition of the preceding theme. The percentage of aberrant theme-transitions progressively increased from pre-exposure to exposure, and again from exposure to post-exposure condition, but the result was not statistically significant (χ^2_2=3.273, p=0.195).

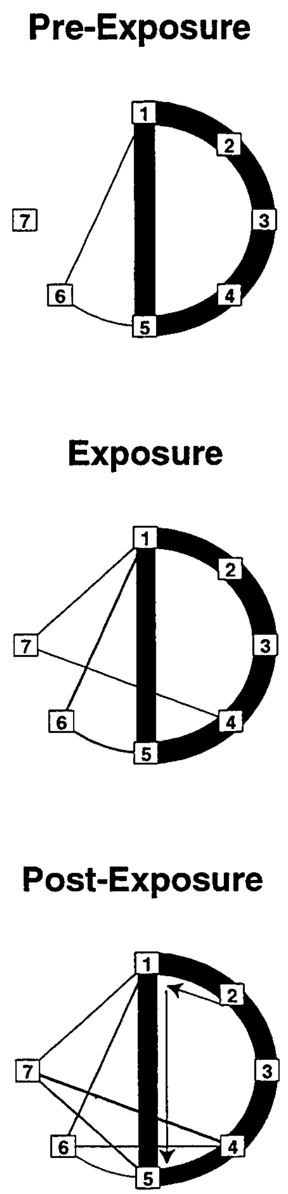

Figure 6 - Theme transition diagrams for the three experimental conditions. Transitions are clockwise except where marked with an arrow, and the relative thickness of the lines between themes reflects the proportion of transitions from one theme to the next. Themes are numbered as defined above. The percentage of songs with aberrant transitions was 5.6, 13.3, and 25.0 in the pre-exposure, exposure, and post-exposure conditions, respectively.

3.3 Cessation of song

Of the 18 playback follows (see Table 1 page 7), the focal stopped singing during the exposure condition (i.e. between the first and last LFA transmission in a playback cycle) in 9 cases. Of these, 4 stopped during a join with another animal and 5 stopped without joining. The maximum received level of the LFA sonar does not appear to be a good predictor variable either of the likelihood of song cessation (t-ratio = 0.518, p = 0.604) or changes in mean song duration (t-ratio = 1.017, p = 0.309). Some singers exposed to high maximum received levels did not stop singing while singers exposed to low received levels often did stop. Likewise the increase or decrease of average song duration did not scale by the maximum received levels (Fig. 7).

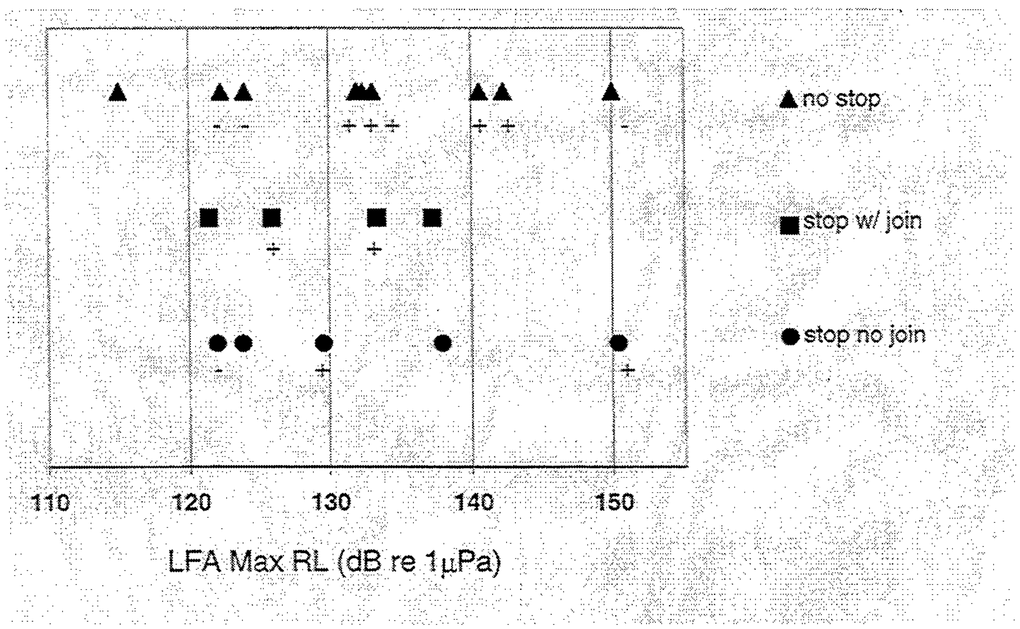

Figure 7 - Response of singing humpback whales as a function of the received level of the loudest ping (LFA Max. RL) during the playback period. The (+, -) symbols show whether the 13 singers increased or decreased average song duration during exposure condition. Note that the response of singers, either stopping or changing the duration of their songs, does not appear to have been affected by the maximum received level.

4. Discussion

These preliminary results suggest that the LFA sonar had an effect on the acoustic behavior of singing humpback whales and that different individual whales reacted differently. Since song is associated with reproduction, widespread alteration of singing behavior could affect demographic parameters or alternatively could represent a successful strategy to compensate for interference from the sonar.

The model III ANOVA results showed that singers increased the duration of their songs during the exposure condition by an average of 29% (p=0.047, power=50%). This is a particularly strong result given the low power of the test and the small sample size (n =6). Song duration returned to baseline after the one-hour playback cycle suggesting that the increase in song length was a short-term effect. The result of the same test on song length of 13 singers across two experimental conditions (pre-exposure and exposure) gave a lower P value and a decrease in statistical power (model III ANOVA, $F_{1,12}$=3.260, p=0.096, n=13, power=32%). High variability in individual responses and small sample size account for the observed decrease in statistical power. A larger sample size would be advisable to confirm this effect.

Theme order was not altered by the LFA playback, suggesting that increased song duration during the experimental condition resulted from increased duration of individual themes within a normal song structure. Given the structure of humpback whale song, an increase in theme duration could result from either an increase of phrase repetition in each theme and/or an increase in phrase duration. We are currently counting and measuring the duration of phrases, and hope to elucidate which feature changes resulted in increased song duration.

Amongst the 18 playback follows, in 9 cases the whale stopped singing during the exposure condition. Four stops were associated with a join with another whale and may not have been related to the playback. The song cessation data presented in Fig. 7 were previously reported in a project summary ('Quicklook') based upon field notes (Fig. 15 in Clark & Tyack, 1998). After detailed analysis of the spectrograms a few minor corrections were made to the figure, but our conclusion is consistent with that of the 'Quicklook' report (Clark & Tyack, 1998). Previous studies of avoidance reactions, especially in migrating whales have suggested a dosage-response relation in which whales are more likely to respond at a higher received level of noise exposure (Richardson *et al.*, 1995). This does not appear to be the case for song cessation or changes in song duration in this study. Singers exposed to the highest maximum RL did not stop singing while some singers exposed to a low RL did stop. Likewise no pattern was found in song length vs max RL.

The difference observed in the behavioral response of singing humpback whales could reflect differences in the behavioral context, motivational state of the whales (e.g. presence of females or other males nearby etc), and/or in the composition of the population of singers. Song displays produced by males are thought to function in female mate-choice and male-male competition, and it is possible that different classes of males

(e.g. size classes, age classes etc.) adopt different strategies (Catchpole, 1986; Emlen, 1976; Hanggi and Shusterman, 1994; Howard and Young, 1998).

The humpback whale mating system has been described as type of lek (Clapham, 1996), and humpback song is the best understood advertisement display amongst cetaceans (Tyack, 1998). Nonetheless, very little is known about the function of song features such as song duration (Chu, 1986), or how the information conveyed by the signal is encoded. Longer song may be more redundant; increasing redundancy could be a simple strategy adopted by singing humpback whales to compensate for the interference from the LFA sonar. Whales joined singers during playback in interactions that were similar to those seen in control conditions, so playback did not completely disrupt normal social interactions, but the sample size is too small for a quantitative comparison of joining rates and subsequent behavior between control and playback conditions. We are also lacking critical data on how females respond to the changes in song features observed in this study, or how the LFA sonar itself might affect female behavior on the breeding grounds. Given our current limited understanding, it is difficult at this early stage of our analysis to predict the biological significance of the short-term effects that we observed. We hope that additional data analyses and further research efforts will help in the interpretation of these results.

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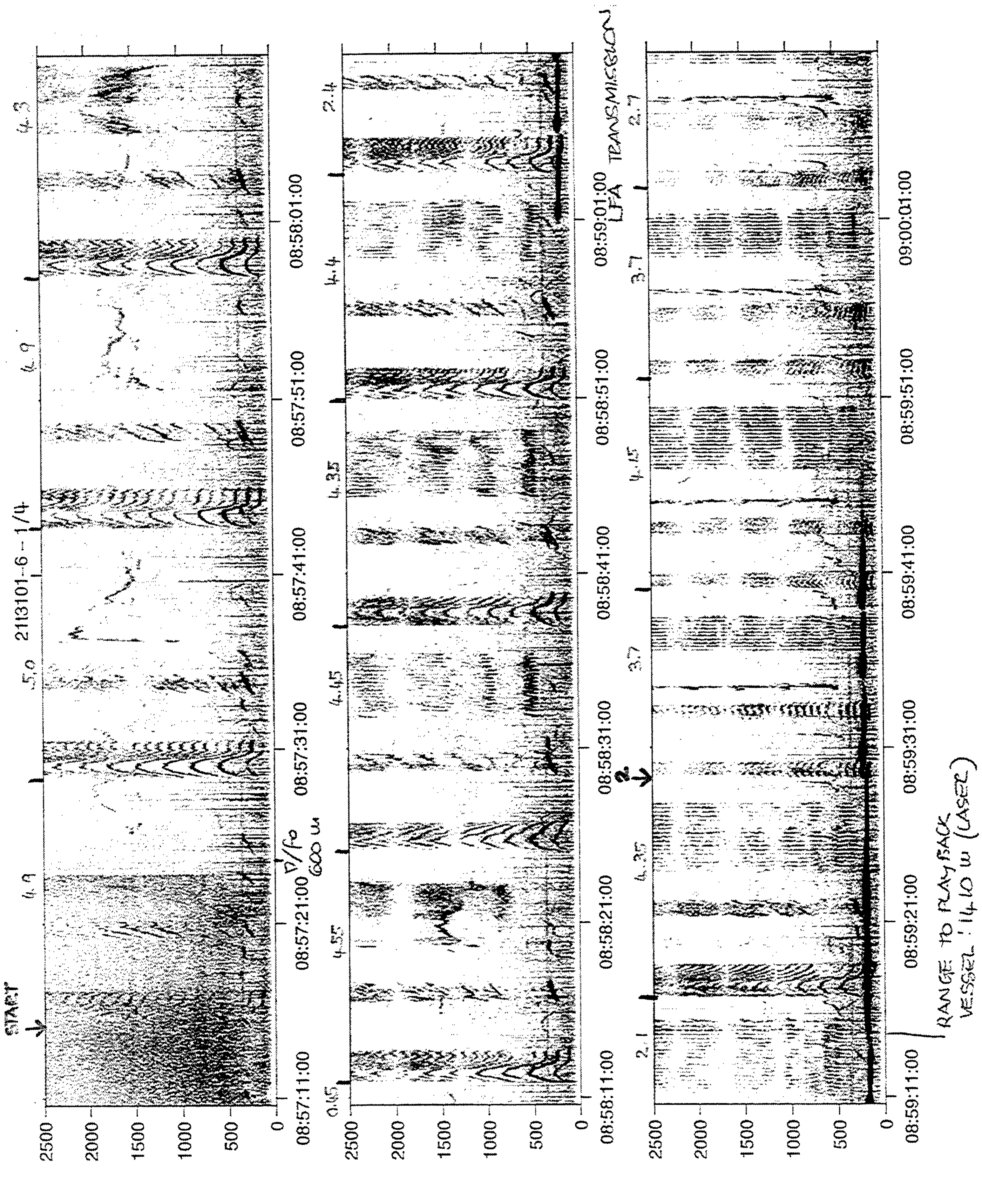
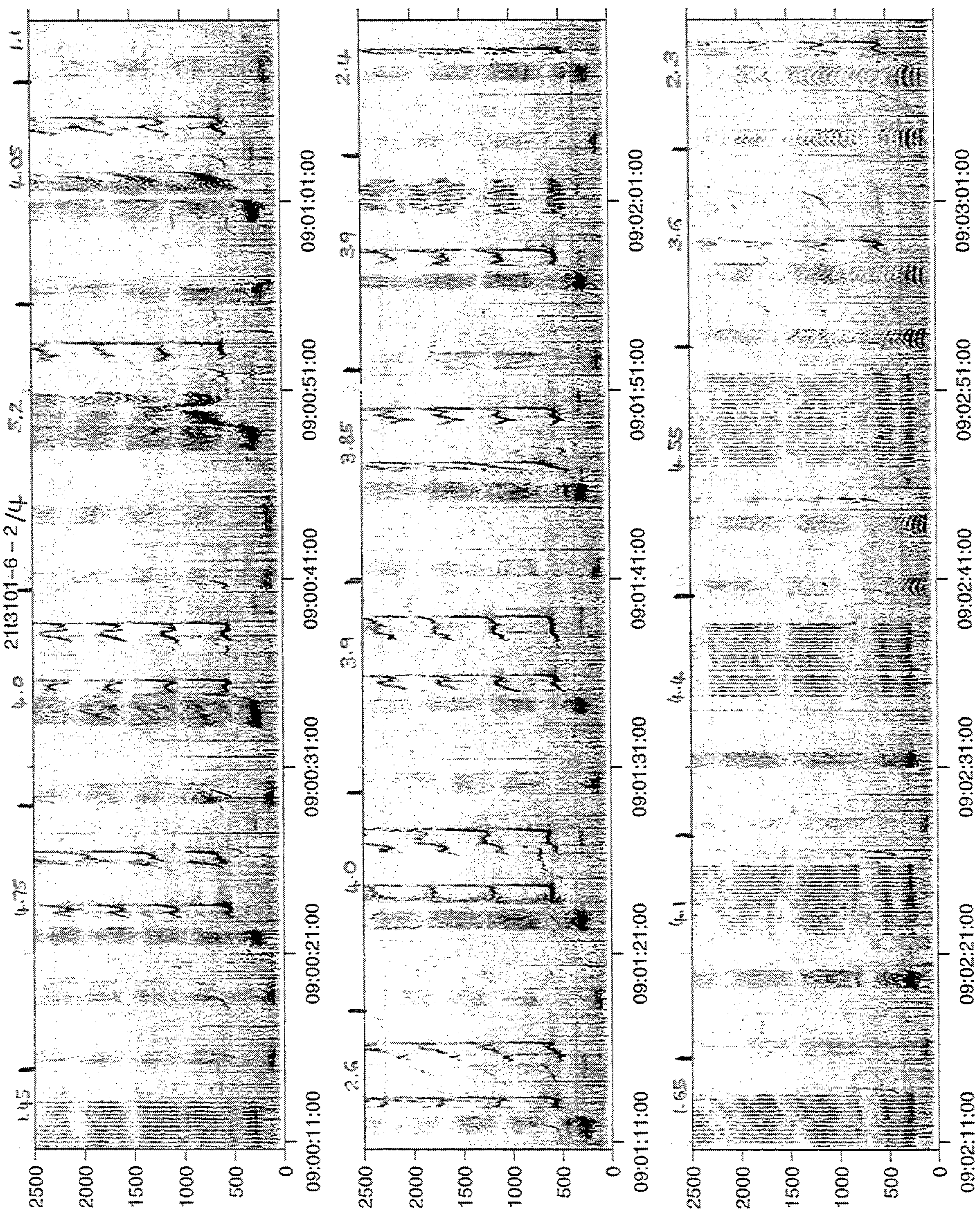
Appendices

A.1 Example of song spectrogram

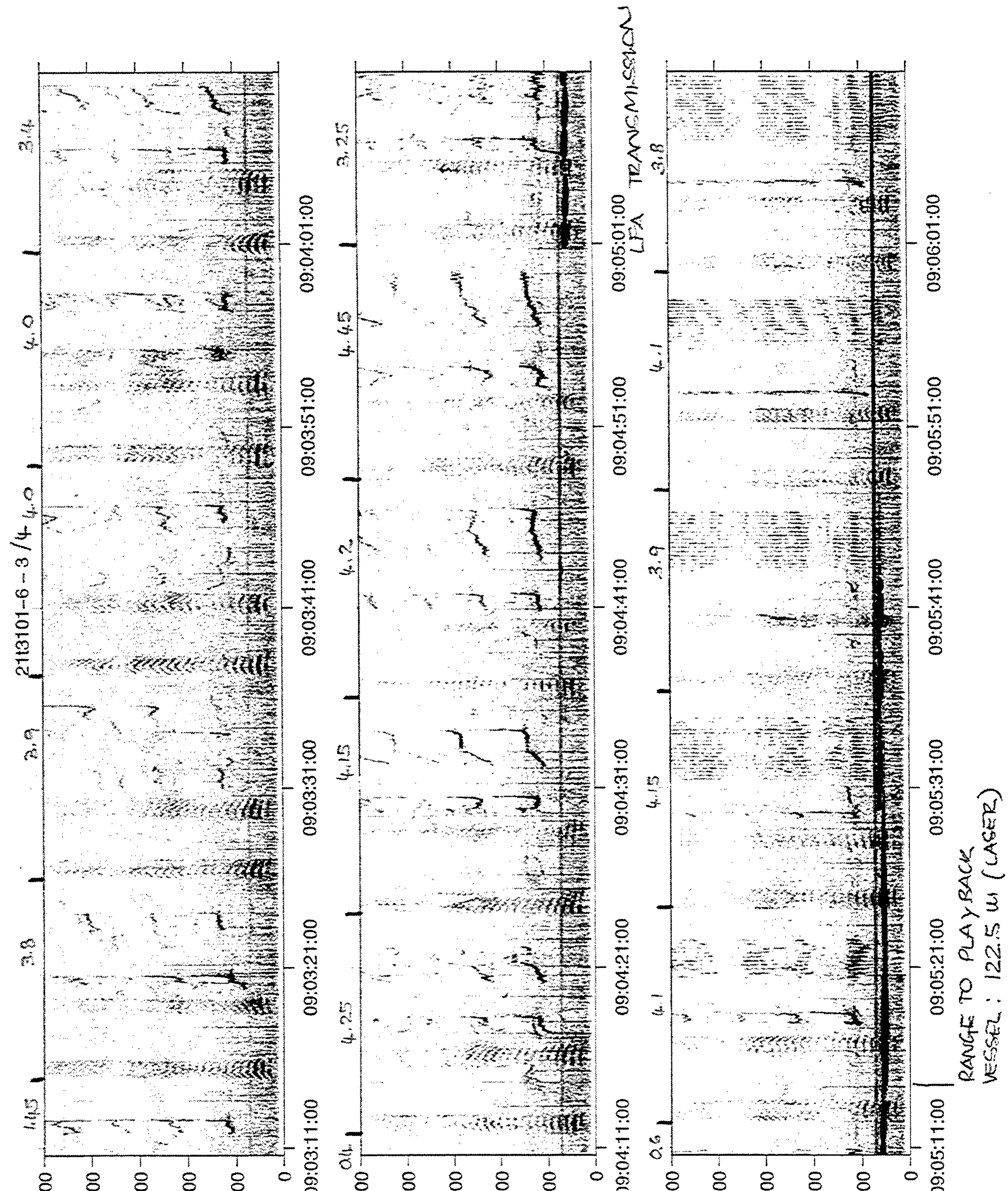
The song shown in the following spectrogram was recorded on the 10 of March 1998 off the Big Island (Hawaii). Time on the X-axis is Hawaiian time (Hawaii = - 11GMT), each line represents 1 minute (total of 3min/page). The start and the end of the song are noted with an arrow. The beginning of a new theme is marked with an arrow and a progressive number starting from 1. Vertical lines on the upper edge of the spectrogram separate phrases, numbers hand-written between those lines express phrase duration in cm. Fluke-out time and surfacing time (first blow) with concurrent distance of the focal whale from the observation vessel are scored at the bottom of the spectrogram.

On the spectrogram are also visible: A) noise from acceleration of the observation vessel just before the whale dives or surfaces (darkening of background). B) noise from the playback vessel (continuous line at 400 Hz). C) LFA transmissions (the first starts @ 08:59:00, and the second @ 09:05:00) with measured ranges to the playback vessel.

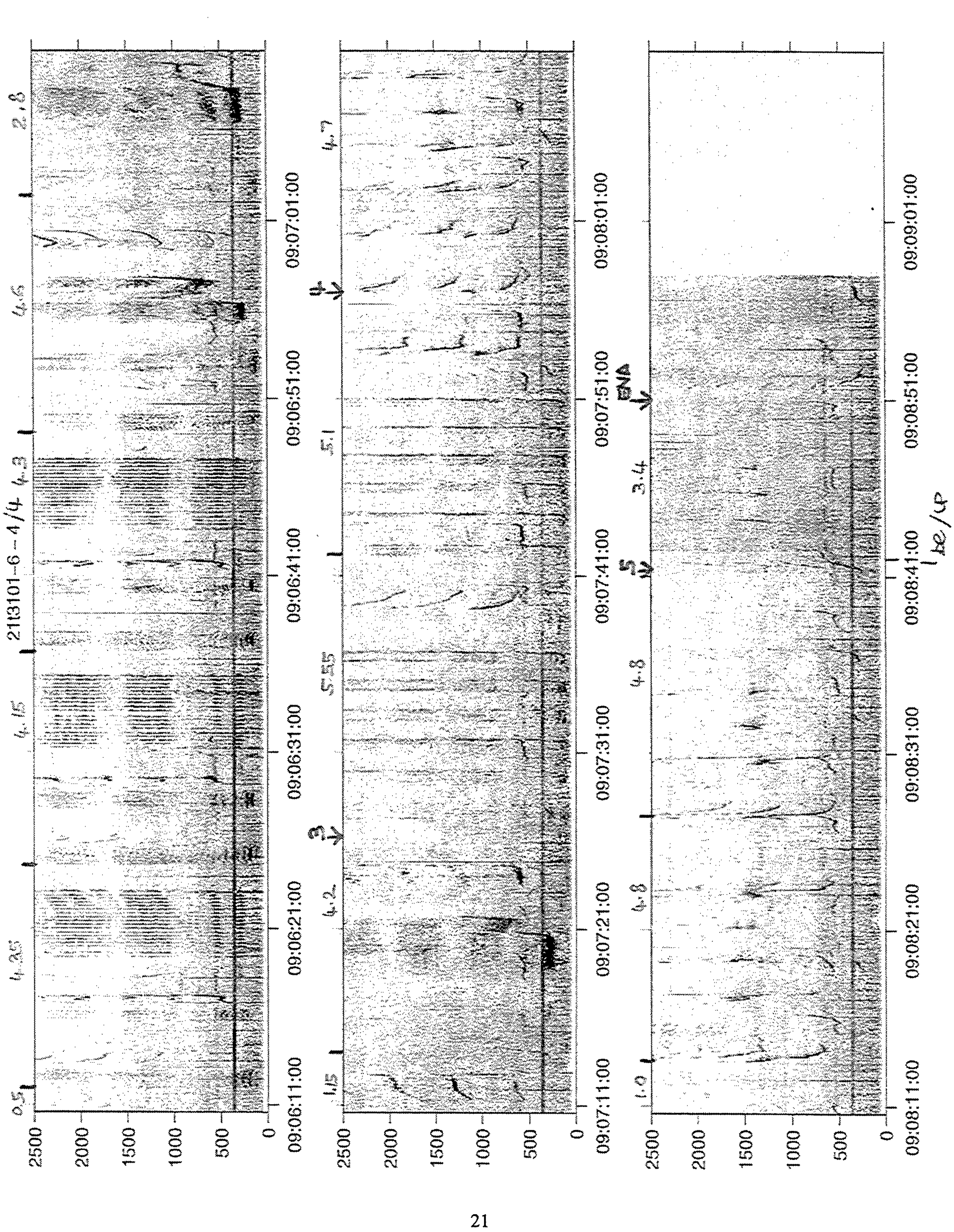

211310l-6 - 1/4
START
TRANSMISSION
LFA
RANGE TO PLAYBACK
VESSEL : 1410 m (LASER)
V/Fo
600 m
2500
2000
1500
1000
500
0
08:57:11:00
08:57:21:00
08:57:31:00
08:57:41:00
08:57:51:00
08:58:01:00
08:58:11:00
08:58:21:00
08:58:31:00
08:58:41:00
08:58:51:00
08:59:01:00
08:59:11:00
08:59:21:00
08:59:31:00
08:59:41:00
08:59:51:00
09:00:01:00



21310I-6 - 2/4
2500
2000
1500
1000
500
0
09:00:11:00
09:00:21:00
09:00:31:00
09:00:41:00
09:00:51:00
09:01:01:00
09:01:11:00
09:01:21:00
09:01:31:00
09:01:41:00
09:01:51:00
09:02:01:00
09:02:11:00
09:02:21:00
09:02:31:00
09:02:41:00
09:02:51:00
09:03:01:00



2113101-6 - 3/4
09:03:11:00
09:03:21:00
09:03:31:00
09:03:41:00
09:03:51:00
09:04:01:00
09:04:11:00
09:04:21:00
09:04:31:00
09:04:41:00
09:04:51:00
09:05:01:00
09:05:11:00
09:05:21:00
09:05:31:00
09:05:41:00
09:05:51:00
09:06:01:00
2500
2000
1500
1000
500
0
TRANSMISSION
LFA
RANGE TO PLAYBACK
VESSEL : 122.5 m (LASER)


213101-6 - 4/4
2500
2000
1500
1000
500
0
09:06:11:00
09:06:21:00
09:06:31:00
09:06:41:00
09:06:51:00
09:07:01:00
09:07:11:00
09:07:21:00
09:07:31:00
09:07:41:00
09:07:51:00
09:08:01:00
09:08:11:00
09:08:21:00
09:08:31:00
09:08:41:00
09:08:51:00
09:09:01:00
lbe/up

A.2 Song analysis data form.

LFA3 - Hawaii 1998 - Exp. phase: pre / exp / post

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Date: 10 MARCH Focal # 1 Song # 6 Song duration: 239.35 Tot. no. of phr.:

Presence of other singers (0, 1, >1): >1 Tape #: 21T Theme order: 1,2,3,4,5 No. of pings: 2

	Theme 1			Theme 2			Theme 3			Theme 4			Theme 5			Theme : 2		
Dur	46.15			163.8			10.65			15.3			3.4					
# of phr.	10			40			2			3			1					
Phr. #	dur (cm)	type (c/d)	ping (1/0)	dur (cm)	type (c/d)	ping (1/0)	dur (cm)	type (c/d)	ping (1/0)	dur (cm)	type (c/d)	ping (1/0)	dur (cm)	type (c/d)	ping (1/0)	dur (cm)	type (c/d)	ping (1/0)
1	4.9	c	0	3.7	d	1	5.55	/	2	5.7	/	2	3.4	/	2	4.15	c	2
2	5.0	c	0	4.15	d	1	5.1	/	2	4.8	/	2				4.2	c	2
3	4.9	c	0	3.7	d	2				4.8	/	2				4.45	c	2
4	4.75	c	0	4.15	d	2										3.85	d	1
5	4.55	c	0	4.75	c	2										4.1	d	1
6	4.45	d	0	4.0	c	2										4.15	d	1
7	4.35	d	0	5.2	c	2										3.9	d	1
8	4.4	d	1	4.05	c	2										4.1	d	2
9	4.5	d	1	3.7	c	2										4.3	d	2
10	4.35	d	1	4.0	c	2										4.35	d	2
11				3.9	c	2										4.15	d	2
12				3.85	c	2										4.3	d	2
13				3.9	d	2										4.6	c	2
14				4.05	d	2										3.95	c	2
15				4.1	d	2										4.2	c	2
16				4.4	d	2												
17				4.55	d	2												
18				3.6	c	2												
19				3.75	c	2												
20				3.8	c	2												
21				3.9	c	2												
22				4.0	c	2												
23				4.0	c	2												
24				3.8	c	2												
25				4.25	c	2												

A.3 Song duration by focal whale.

Duration of complete songs recorded from each humpback whale by experimental condition.

Focal Whale	Song duration (min)		
	pre-exposure	exposure	post-exposure
3011	10.95, 11.83, 10.26	13.87, 11.35, 12.47	
3021	14.98, 9.32, 5.03, 6.62, 8.36, 3.52	7.08	
3031	6.23, 10.27, 6.36	4.12, 8.72, 8.01, 12.18, 14.82, 19.26	9.58, 3.71, 1.28, 3.91, 9.35
3041	9.42, 10.86, 13.23	14.91, 9.75	
3042	11.39, 14.87	14.15, 7.87, 7.34, 14.58	
3052	13.51, 21.46, 13.15	13.45, 14.74, 7.63, 11.68	
3101	7.14, 12.58	12.07, 14.61, 11.65, 10.40, 11.09, 5.42	7.19, 5.20, 4.96, 5.59, 22.52, 15.35, 16.51, 11.55
3102	18.09, 19.25	15.30, 20.76, 19.14, 17.64	14.40
3171	7.54, 4.36	13.69, 11.18, 10.19, 7.22	7.74, 6.20
3181	6.27, 12.68, 8.97	16.58, 15.43, 19.21, 15.07	12.09, 8.37, 14.43, 10.51
3271	12.22, 12.19, 11.20, 17.46, 12.34, 13.47, 9.86	12.68, 11.23, 9.38, 20.21	17.38, 13.13, 11.77
3281	29.05	53.86, 28.99, 23.55	
3291	7.05, 7.40, 15.18, 8.63, 8.98	16.70, 7.61	

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16. Abstract (Limit: 200 words)

The singing behavior of humpback whales exposed to SURTASS-LFA sonar was monitored in Hawaii during March 1998. An observation vessel towing a hydrophone array followed individual singers continuously recording their songs and the received level of the sonar near the whale. At least 2 complete songs were recorded before commencing a 60min 42s long playback, which consisted of ten 42s signals transmitted every 6 min. by a U.S. Navy vessel. Observations continued into the post-exposure period. Song spectrograms were broken into themes and phrases using visual analysis and aural scoring. 23 focal follows were conducted; 5 were control follows with no playback. In 9 follows the whale sang throughout the playback, in 4 the whale stopped singing when it joined another whale and in 5 it stopped presumably in response to the playback. We recorded at least one complete song in all three experimental conditions from six individuals. These singers sang longer songs during (13.75min) than before (10.68min) or after (10.58min) the playback (model III ANOVA, p=0.047, n=6). No differences were found in theme order (χ^2_2=3.273, p=0.195). Song cessation and song duration responses did not scale with sonar received level. High variability in individual responses may indicate that some males were more sensitive to the sonar than others.

17. Document Analysis a. Descriptors

Humpback Whales

Disturbance

Sonar

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c. COSATI Field/Group

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